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Assessment of retrofitting measures and solar systems' potential in urban areas using Geographical Information Systems: Application to a Mediterranean city

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ABSTRACT

Energy efficient management of urban environment is undoubtedly a challenging task. Although the topography of cities and their urban built environment are considered as the main layers for environmental analysis, further geographical data has to be taken into account as well. In particular, economic and social data should also be considered on spatial level, as they highly affect the need for energy conservation measures. Furthermore, land and building uses, urban mobility and transactions are also crucial factors that influence energy use and management. Within this framework, this paper examines the establishment of a methodology approach in order to estimate energy conservation and solar systems potential in urban environments, based on the implementation of geoinformatics decision-making tools into a fine-scale analysis over an extended geographical area. All above multi-criteria variables can be efficiently analyzed by applying Geographical Information System (GIS) tools, which are particularly applied for the establishment of the proposed methodology. The scope of the paper is to deliver an integrated assessment tool, in order to aid researches as well as public bodies for the implementation of energy policies concerning the urban built environment. A case study of the urban area of Thessaloniki in Northern Greece is presented focusing on the evaluation of current energy performance and possible retrofit measures for the existing urban building stock, especially for typical residential multi-family (MF) buildings. Conclusively, the general outcome obtained by current research, indicate that denser urban areas perform limited potential both for retrofitting interventions on buildings' envelope and solar systems applications, apart from the quality and the age of building constructions.

Contents

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1. Introduction

The energy dependency that followed the first oil crisis in 1973 and the Iranian Revolution in 1979 brought energy issues to the forefront [1]. It is remarkable that more than 50% of the EU's energy is supplied from countries outside the Union and this percentage is constantly growing [2], thus the primary concern of the European Community is energy conservation. Therefore, in 2007 the European Council has set demanding goals for 2020 concerning energy deficiency and climate change, such as the reduction of greenhouse gas emissions by 20%, the increase of the renewable energy share to 20%, and the improvement of energy efficiency by 20% [3].

Apart from the efforts made on European level, members of South East Europe also attempted to set specific targets as regards energy dependency and efficiency. Namely, Mihajlov [4] reminds us of the Athens Agreement, signed on 8 December 2003 [5], which eventually led to the establishment of the Energy Community of SE Europe on 25 October 2005 [6].

Additionally, climate change and the need for CO_2 emissions' reduction are affecting political decisions and respective planning objectives, a tendency that is expected to progress for the next decades. In this framework, new strategies concerning urban planning are essential for enabling large-scale housing and infrastructure development [7]. Furthermore, over the past century only a few percentages of the world's population lived in cities, whilst according to the United Nations, nowadays this percentage reached 50% and is expected to rise in the long run [8]. Respective data published by EAA indicate even larger concentrations, namely by 2020 approximately 80% of Europeans will be citizens in urban areas, whilst in some countries the quote will reach 90% or even more [9]. Consequently, the ascending human concentration in cities determines sustainable urban planning. In this line of thought, cities should no longer be studied as autonomous bodies. On the contrary they should be perceived as a part of a global network, which must satisfy the various increasing demands of their inhabitants, and more importantly, it should do so within a framework of urban sustainable development [10].

Thus, urban sustainability is a research field that constantly gains interest and significance. With respect to various aspects that determine the energy efficiency of the urban built environment, numerous studies have proposed methodology approaches and evaluation tools in order to plan intervention scenarios in a more efficient way [11–15], many of which focus on the reduction of CO_2 emissions and as a result the minimization of electricity loads as well as the utilization of renewable energy sources (RES) [16,17,7]. Besides energy efficiency Owens stresses that the effectiveness of such measures must involve and satisfy democratic criteria. Otherwise, in case of inequality between these two aspects, the energy efficiency legal and support systems might be unsuccessful [1]. Meanwhile, Yiftachel and Hedgcock argue the importance of the social aspects concerning urban and regional development and underline the relation between urban social sustainability and urban planning [18]. Moreover, according to James Madison "knowing something about the characteristics of local populations improves local governance is accepted as a basic premise in planning, politics, and policy analysis" [19]. Therefore, urban sustainable development reflects the polymorphic synthesis of numerous parameters, which are connected to urban life.

With respect to energy conservation, retrofitting of urban buildings is often equivalent to retrofitting of cities as a whole. As cities differ in their structure, their typology and like so, in their energy profile, developing a flexible evaluation tool of their energy performance is a rather complex procedure. The scope of this paper is to suggest a holistic evaluation approach as a part of a bottom-up methodology in order to evaluate the present state of the art concerning energy efficiency in urban areas, as well as respective retrofitting measures and their impact on the urban built environment. Based on detailed buildings' classification, parameter analysis and spatial analysis, the proposed methodology can be equally implemented by individual planners, municipalities, prefectures, other public authorities, as well as by ministry bodies on a national level.

However, in order to ensure the efficiency of this tool data, various data sources, which are hard to retrieve, are necessary. Crawford and French underline the need for exquisite and continuous collaboration between planners, regulators, development agencies and, last but not least, developers in order to achieve effective zero-carbon urban development at both micro- and macro-scale [7].

Unfortunately, in Greece little progress has been made towards this direction. The existing research on the residential building stock focuses on topics such as (a) energy consumption estimation (b) building classification and (c) retrofit scenarios assessment. Equally, with respect to residential energy consumption, most researchers examine heating and electricity demands [20–25]. Rapanos and Polemis [26], for instance, present the determinants of residential energy demand in Greece for the

period 1965–1999. Moreover, early in 1991 Assimakopoulos et al. focused on the relation between the structure of Greek households based on various socioeconomic characteristics [27]. In similar way, Papadopoulos et al. [15] perform a bottom-up building physics based feasibility study for Northern Greece. Additionally, Santamouris et al. [28] gather information about 1110 households in Athens, by using a questionnaire that lead to remarkable conclusions concerning the relation between socio-economic characteristics and the energy behavior of households. In correspondence with data collection strategies, Doukas et al. propose a methodology for the collection and elaboration of renewable energy sources, expenditure and end-use efficiency data [29–31] whilst Assimakopoulos describes a multivariate statistical technique [32] and Sardianou analyze survey statistical data so as to evaluate space heating factors that affect Greek residential stock and propose efficient retrofit policies [33,34]. As regards building classification, Santamouris et al. study the energy performance of school buildings according to their typology, based on intelligent clustering techniques [35]. Additionally, Balaras et al. group single and multi-family (MF) buildings according to their year of construction [36] and analyze their energy performance as well as respective energy conservation measures using the EPIQR (Energy Performance, Indoor Air Quality, Retrofit) methodology [37]. It is important to notice, that no holistic assessment methodology was yet presented, which eventually deal with the multi-complex issue of Greek cities.

Concluding, although several researches on urban sustainability are based on GIS analysis, only few examples of extensive assessment tools have been published. Hence, most of GIS based analysis concerning energy performance of cities, study only one evaluation parameter, such as RES implementation [38], or infrastructure and CO_2 emissions [39] or air pollution [40]. The scope of this article is to redress these literature inadequacies by making a first step in exploring the concept of GIS-based multi-variable energy behavior assessment of the urban residential buildings and the degree in which this concept impacts on sustainable urban planning.

In current paper, a case study is presented regarding the city of Thessaloniki, a typical urban Mediterranean region characterized mostly by residential multistorey buildings, whilst emphasis is laid on the integration of GIS into the proposed assessment tool. The demonstrated evaluation GIS methodology builds on a bottom-up building physics and statistical based assessment tool proposed by Theodoridou et al. [41]. The main scope of this paper is to assess the energy behavioral pattern of the case study area and explore the potential for retrofit actions, concerning the buildings' envelope and the implementation of RES. The respective outcomes will form the foundation for a future targeted and in depth energy efficiency policies' planning, which will address matters of energy conservation, environmental impact and overall feasibility assessment of such measures.

2. Methodology approach

2.1. Theoretical background

The main goal of the proposed methodology is the development of a valid integrated assessment tool, applicable for urban built environment, which will particularly focus on the residential stock and its energy performance. This tool is applied for a typical Greek city, namely Thessaloniki, the second largest one in the country. After a thorough elaboration of the available statistical data, as well as a survey and literature research, a GIS based analysis is carried out concerning the structural typology of a typical urban environment, completing an impact assessment of various retrofitting scenarios on city level (Fig. 1).

As depicted in Fig. 1 the proposed GIS based methodology is divided to two phases; during the first phase the urban built environment and the nature of the urban structure are analyzed, whilst during the second one the effect of various energy conservation measures on the city's energy performance are being examined.

In order to ensure safe conclusions, a thorough investigation of the building stock under study is of vital importance, as described by Theodoridou et al. [42]. Exclusively, this analysis will lead to a typological classification of the built urban environment that facilitates straightforward planning of retrofitting measures. Such methodological procedures presuppose access to a variety of data, exported from a combinative elaboration of miscellaneous information. Hence, likely to the most evaluation models, the efficiency of a bottom-up approach is strongly affected by the precision and diversity of the updated and relevant available data. The more direct access on these data is provided, the more pertinent conclusions can be drawn and, therefore, the more optimized interventions can be planned. However, in Greece there is rather limited access to such official GIS data, a drawback also underlined by Nghi and Kammeier [43]. In our case, digital mapping information was mainly acquired by the corresponding Municipalities. More specifically, they developed GIS maps, within the scheme of past European funded projects, importing information both on building unit and building block level concerning mainly infrastructure construction parameters, buildings' and land uses as well as public and green spaces. Inevitably, the elaboration of this information can lead to further conclusions that thereafter, can easily be linked to public services and urban management. Moreover, enriching these data with national based information and scientific research outcome will definitely set out the broader spectrum for the application of the proposed methodology.

In Greece, little progress has been made in terms of integrated energy related assessment tools, especially as regards urban areas. Apart from the research regarding energy behavior of certain buildings' typologies and top-down macro-economic assessment methodologies [26,20–23,37,29,30–35] the majority of the studies is based on plain energy simulation software and generalized census results [15,28,35]. With respect to the aforementioned urban planning trends proposed by the global research community, this is a rather outdated approach, which cannot carry on supporting future sustainable urban development policies. Hence, new flexible and effective tools must be developed, which will promote efficiently the introduction of large scale energy efficiency measures. In this line of thought, the methodology proposed by Theodoridou et al. [41], included the elaboration of GIS data outcomes, which will provide us with important information as regards the implementation of various retrofit scenarios, specially designed for cities and urban built environment. The proposed methodology is rather flexible and can therefore be applied for different city structure typologies.

2.2. Buildings' classification

Swan and Ugursal argue that it is profound to control the energy consumption of the residential sector mainly due to its polymorphic typology, the variety of the occupancy behavioral profiles, as well as technical, cost and privacy parameters that complicate the procedure of data collection, in-situ measurements and elaboration of energy indicators [44]. Due to these reasons and in order to plan retrofit scenarios for the urban built environment, the classification of buildings becomes of vital

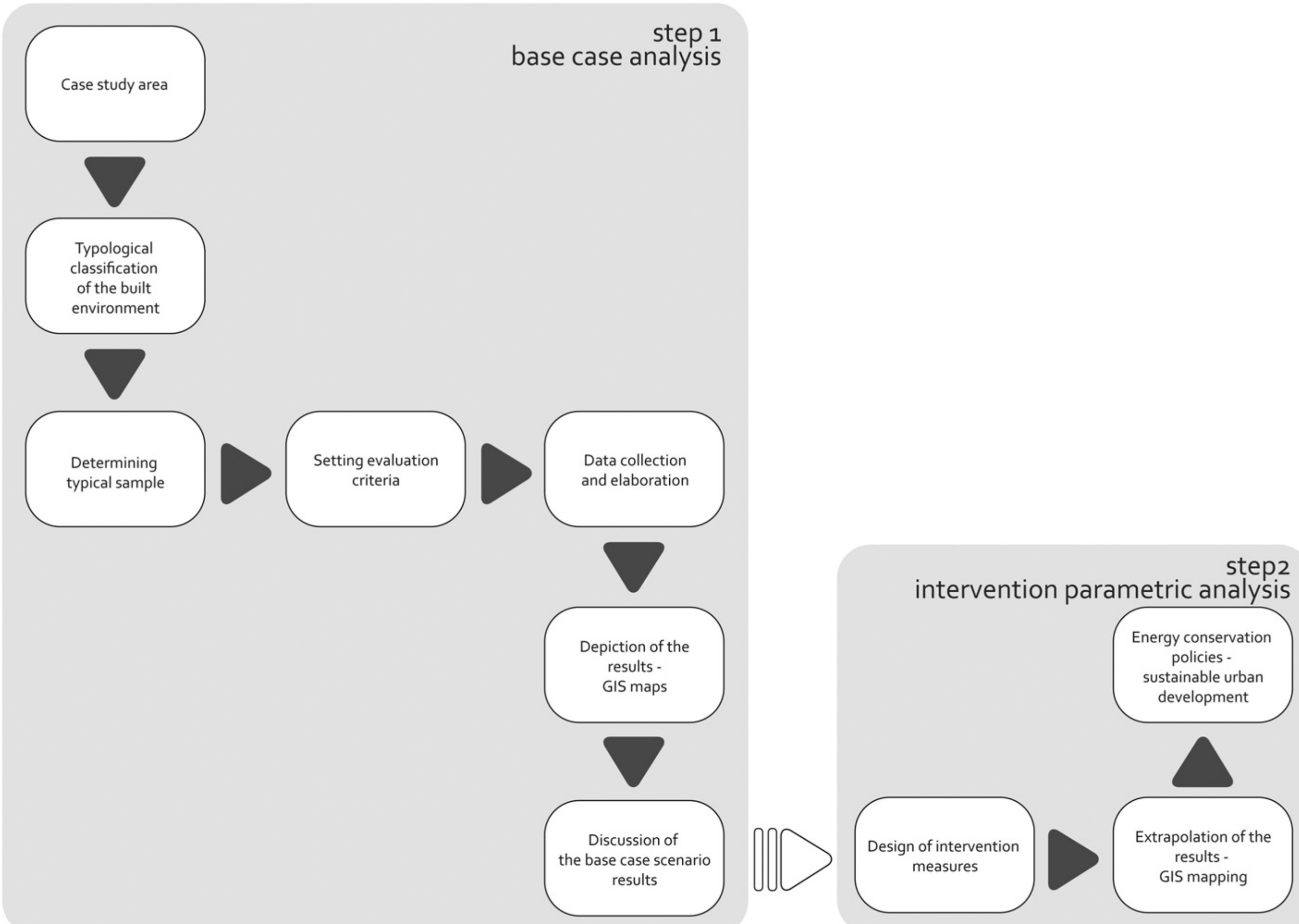

Fig. 1. Methodology approach of the GIS based assessment tool.

importance. Several studies used an age-based classification [45–52,36,42], which determines construction practices and materials to a great extend. Similarly, Barelli et al. [53] propose a further classification mainly dependent on dimensionless energy performance values.

Gadsden et al. [54] propose a multi-criteria analysis of a solar energy planning (SEP) system for the urban domestic sector. It is of great interest to notice, that their work recognizes the problem of (a) energy consumption estimation, (b) buildings' classification and (c) energy modeling in general and so they suggest a holistic evaluation methodology, which takes into consideration all the above factors. Initially, as far as energy consumption information is concerned, they propose a monthly energy consumption tool rather than an annual one, in order to gain information on a seasonal basis. Moreover, they use a buildings' classification that is based on the year of construction, the building form and the attached to other buildings or detached building position, whilst they develop a customized GIS tool that allows the recognition of the outlines of buildings as closed polygons. They further believe that this classification procedure enables the usage of available statistical data from respective surveys (e.g. English House Condition Survey (EHCS)) concerning the energy performance of buildings. Afterwards, various intervention scenarios are studied in terms of RES potential. Therefore, although this research focuses on RES and the urban built environment, the concept and the methodology approach presented by Gadsden et al. progresses on the same wavelength as ours.

More specifically, our GIS-based methodology builds on a typical classification of the building stock under study. According to the characteristics of each class, data are produced, which describe features mainly about buildings' typology, usage, number of floors, height, dimensions, orientation, RES potential and shading issues.

In our case study, the typical classification regarding Greek urban residential buildings, proposed by Theodoridou et al. will be applied [42]. Namely, four (4) typical buildings regarding the main construction classes met in the urban Greek environment are being analyzed, taking into consideration both their actual and calculated energy performance. These classes are Class B2 (1960–1980), Class C (1981–1990) and Class D (1990–2010) [42]. The typical constructions refer to MF-buildings and are organized as shown in Table 1.

The four categories of Table 1 are characteristic for the majority of the sample. In addition, smaller subcategories are being introduced in order to describe slight deviations. These mainly concern the state of attachment and therefore, by and large, refer to Class C and Class D. Hence, MF3 building was also studied as fully detached, as well as attached to one building, whilst MF4 building's energy behavior was determined in the case of a row system construction, thus attached from one and two sides respectively. For Class B2, MF1 building was considered also as attached only to one side. Moreover, buildings constructed before 1960 were not studied, due to the lack of typological pattern and the fact that they are often characterized by landmark use.

With respect to the outcomes of the GIS-analysis, these buildings will represent typical blocks and areas within the urban

Table 1
Typical buildings of our case-study area.

Code	Class B2 (1960–1980)		Class C (1981–1990)	Class D (1990–2010)
	MF1	MF2	MF3	MF4
Year of construction	1969	1976	1985	1998
Location	Municipality of Thessaloniki	Municipality of Kalamaria	Municipality of Kalamaria	Municipality of Kalamaria
Short description	Row-system	Detached, with Pilotis	Row-system, with Pilotis	Detached, with Pilotis

built environment, enabling an overall assessment of the city's energy performance and an extrapolation of the results related to intervention scenarios. Detailed information about the case-study area and the input data are presented in Section 4.

2.3. Energy efficiency of buildings and retrofit scenarios

Energy efficiency of urban buildings is affected by numerous aspects. Most of these parameters are strongly connected to urban density and structure, as well as to respective derivatives, such as attachment to other buildings, solar radiation and A/V ratio, strongly influencing cooling, heating and ventilation loads, as well as indoor air quality and thermal comfort. Hence, in the proposed methodology, urban buildings are examined by means of their built environment and classified accordingly. Specific buildings are being studied as typical examples of various building blocks, which in turn, reflect a common urban typology structure. Each of the aforementioned parameters, are strongly connected to the energy performance of the buildings under study, thus they determine the energy profile of typical city areas.

With respect to energy efficiency management of the building stock several studies were developed over the past years. More specifically, there are six prominent bottom-up methodology approaches based on building physics evaluation that are applied for the UK housing stock, which all share the same evaluation tool named BRE Domestic Energy Model (BREDEM) and study the CO_2 emissions reduction [55]. In addition, as regards the residential stock, Míguez et al. deliver analytical information concerning the energy policies implemented in 15 European countries, a state-of-the-art referring to the year 2004, though describing a tendency that still remains strong in Europe as well as worldwide [14]. In this framework, energy certification became a prominent tool for the improvement of the buildings' energy behavior since the early 1990s [56].

Furthermore, several researchers dealt with the energy performance of residential buildings, for various climates and using different approaches; Filippín et al. study the energy performance of MF-buildings in a temperate-cold climate in Argentina [57], whereas Papadopoulos et al. present a feasibility study for energy conservation measures for various buildings' typologies among residential buildings [15]. In particular, for the evaluation of the respective results, criteria such as the A/V ratio, the building form, the heating systems and the year of construction are taken into consideration. Moreover, with respect to Jordan's energy sectoral consumption of electricity, the residential stock demonstrates the highest percentage up to 35% followed by industry with 29% and other usages [58]. Hence, Al-Ghandoor et al. use multivariate regression analysis in order to examine and classify the parameters that determine fuel and electricity consumption [58]. In addition, Wang et al. use multi-criteria decision analysis (MCDA) in order to determine sustainability factors of retrofit policies and show that CO_2 emissions are a common comparison tool for technical, economic, environmental and social aspects [59]. Similarly, as simple retrofitting is a rather outdated goal for many EU-members, Yangang et al. study various retrofit scenarios focusing on the UK building stock in order to meet zero-carbon energy refurbishment standards proposing a hierarchical implementation of the respective technologies [60]. On the same wavelength, Hernandez and Kenny state that crucial assessment criterion is the life cycle energy use thus proposing a relevant methodology applied to the EU Building Energy Rating method concerning Irish residential buildings [61]. In the same line of thought, Sivaraman suggest an integrated life cycle assessment model in order to evaluate energy conservation measures for heritage buildings in Australia, studying specific intervention scenarios [62].

The aforementioned studies reflect the current research state-of-the-art, leading us to a very important conclusion; energy refurbishment of buildings is a matter of classification, evaluation criteria and priorities, assessment procedure, data availability, whilst the issue of flexibility and easy application of the proposed methodologies are of vital importance in order to ensure efficient energy policy making.

2.4. GIS analysis

Urban spatial databases contain both geometry data (coordinates and topological information) and attribute data, i.e., information describing the properties of geometrical spatial objects such as points, lines, and area, making thus Geographical Information Systems (GIS) an indispensable tool for handling these datasets [63]. GIS defined among others as a set of computer tools for the storage, retrieval, analysis and display of spatial data may also be required to supply data to numerical models of spatially explicit urban environmental problems and processes and display the results of these models as cartographically acceptable screen and hard copy images [64].

Hence, in studies to determine availability of renewable resources, GIS are necessary since they can both be used to process data and to demonstrate their local impacts [65,66]. Also, GIS apart from the spatiotemporal analyses and visualization of the resources and demand, can also function as Decision Support System while implementing location-specific renewable energy technologies [67]. Furthermore, due to the spatially explicit information stored and processed within the GIS, urban planners and managers have the potential to address problems at multiple scales of the urban fridge landscape. In example at city level, they can conceive and plan interventions at block, street, neighborhood scale; at building level to propose and design specific conservation and enhancement interventions that pay particular attention to the ecological and energy dimensions [68].

In the cases of decentralized energy planning at district level, energy and environmental planning models and resource energy planning models, examples from Germany [69], China [70], India [71], UK [38], are being presented, underlining the important role of GIS based analysis in energy modeling as regards sustainable planning of rural areas, implementation of RES, wind energy and solar energy planning in urban areas, hence a broad spectrum of research field [72].

Furthermore, for urban planning issues [73], occupancy behavior in residential buildings [74], green roof studies and their impact on urban watershed [75], ecotourism [76], as well as the potential for RES implementation, such as photovoltaic and

various solar systems [38,70,54,77]. Also in the field of sustainable accessibility GIS can be an important assessment tool [78], as well as in the field of stream power [79], climatic assessment methodologies [80], CO_2 emissions produced by vehicles [39], the evaluation of thermal comfort conditions in urban public spaces [81] and air-pollution in the urban environment [40].

Other applications of GIS deal with studies concerning wind energy implementation [71,82,83]. With respect to wind energy policies, Dalton et al. argue that Denmark, among various successful measures, used GIS based site selection tool in order to promote wind energy policies. They also underline the need to adopt similar measures in Ireland, in order to supply premium locations sites for wave energy exploitation, which should include information concerning bathymetry, wave energy data, suitable port locations, nature reserves and many more [84].

Moreover, Marulli and Mallarach developed a methodology for the assessment of landscape and ecological connectivity at regional scale, which was based on mathematical language and developed using GIS [85]. In the same line of thought, Li and Yeh used GIS for the assessment of spatial restructuring of land use patterns in fast growing regions [86], whilst Store and Jokimaki used it in order to estimate spatially explicit analysis of habitat value [87]. Furthermore, Oh presents a methodology approach based on GIS and computer graphics simulation techniques in order to manage urban landscape information and visualize the outcomes of development assignments, called LandScape Information System (LSIS) [88]. Similarly, Stevens et al. developed a GIS based tool in order to predict urban growth, called iCity—Irregular City [89].

In this framework, the proposed GIS methodology aims at the determination of the energy profile for a larger built environment, thus not only for a building unit. In order to achieve this, the GIS data are elaborated in 3D format and can deliver results for vertical, horizontal and shaded surfaces, as well as for typological characteristics that are being described in the following chapters.

3. Evaluation parameters

In order to examine the energy performance of the urban buildings and plan the suitable retrofit measures, the definition of the necessary evaluation parameters is prerequisite. Within this context, GIS is applied allowing us to analyze the potential for renewable energy systems implementation, interventions concerning the buildings' envelope, as well as CO_2 emissions based on energy performance of the buildings under study. The requested variables are depicted in Fig. 2.

In current work, analysis is carried out regarding energy demands and consumptions of a typical existing urban region, namely the city of Thessaloniki in Northern Greece, by applying the described GIS formula. The most important results, which are presented in the following sections, will eventually contribute to the development of an efficient decision making policy concerning energy interventions scenarios in the overall building sector.

3.1. RES implementation

As far as photovoltaic (PV) and solar water heating (SWH) systems are concerned, this paper demonstrates a methodological approach for solar resource availability in urban areas, which combines the capabilities of GIS, aerial object-specific image recognition and existing urban morphology characteristics determination (e.g. density of building blocks, building site layouts, buildings' orientation, height, geometrical shape and envelope configuration etc.). The paper firstly aims at defining solar architecturally suitable rooftop areas for solar technologies in a typical Greek urban region, such as the city of Thessaloniki and secondly indents to compensate in a degree for the lack of methodologies already developed for those purposes and presented in past literature. Furthermore, in current research scheme, solar potential on façade areas is also examined, but neither further details nor any outcome is presented, because this task is still under completion.

Within this framework, it should be remarked that the complexity of the urban environment and building heterogeneity requires, in general, assumptions and input data for the solar energy use computation to be set and applied, which will conclude to safe proposals and information and will not mislead researchers and energy policy makers. Furthermore key to increase the significance of that kind of research is, as supported also by Gadsden et al. [54], to develop an attractive alternative method which will extract acceptably accurate values for solar energy from digital urban maps without the need for time-consuming and expensive site surveys.

Therefore, the primary objective of our research is the recognition of the most significant construction limiting parameters which interfere with solar energy utilization in residential MF-building typologies, which concern the majority of urban building stock in Greece. The second objective regards the formulation of an accepted and validated process and a comprehensive set of rules of thumb for the approximation of suitable areas for PV and SWH use under architectural and solar aspects, which initially, by using digital maps, involve the determination of roof (and façade, in future analysis) architecturally unavailable areas and thereafter the approximation of unsuitable shaded areas. Finally, the paper attempts to account for potential power and energy output by PV and SWH systems compared to baseline energy demands of MF-building typologies for electricity and domestic hot water (DHW).

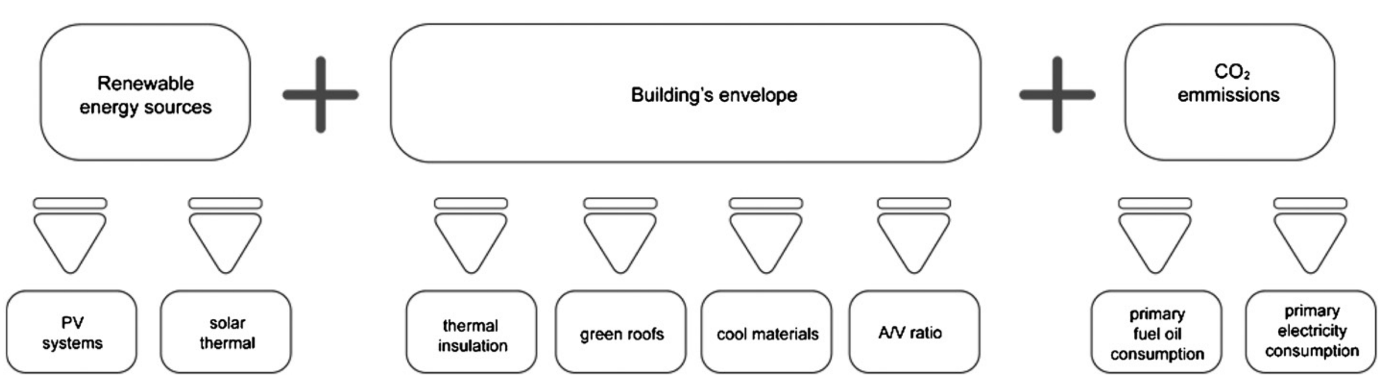

Fig. 2. Evaluation criteria according to the GIS methodology.

Several authors have already applied GIS techniques, empirical rules and statistical analyses quantifying solar energy utilization potential in urban fabric. Some of them took into detailed consideration shading effects and construction restrictions to estimate solar energy use suitable areas in existing building stock, examining a small-scale sample of representative building typologies and then scaling the results on a whole region level, whereas others, for the same purpose, just applied simplified limiting coefficients.

In particular, Winigton et al. [90] develop a five-step procedure for estimating PV potential on rooftop areas, by dividing geographically a certain region, assessing a sample of typical buildings and extrapolating results by applying built areas-population relationships. However, within rooftop PV suitable areas calculation process they simply set parameters such as shading effects and roof component unavailable areas by using literature's relative outcomes. Pillai and Banerjee [91] focus on potential estimation for SWH systems linking successfully micro and macro-level factors from individual end-use to market level, and when it comes to detailed accounting for suitable areas, they assume an arbitrary utilization coefficient, without any detail given. Similarly, Lehmann and Stefan [92] present a mathematical correlation between solar energy usable areas and population density in European Union, albeit total available roof and façade areas are multiplied by a theoretical exploitation factor of 0.9 and 0.66 respectively so as to determine the overall solar suitable areas. Following the same pattern, Yue and Wang [93] evaluate wind, solar, and biomass energy sources in a rural area in Taiwan with the aid of a GIS by taking into consideration several local restrictions, but as far as PV areas are concerned, a 25% of the total rooftop area of buildings is simply assumed to be suitable as for the energy output computation. Moreover, Castro et al. [94] concentrate on forecast of possible future scenarios of grid-connected PV buildings in Spain, without detailed consideration of restrictive installation issues such as shading effects. In the same way, International Energy Agency estimates average PV roof areas for certain member states, but its procedure is not described in detail [95], as well as Suri et al. estimate urban PV potential for EU countries by using CORINE Land Cover and Global Land Cover databases to extract surface data for residential built areas simply by assuming that 1 kWp PV system consists of total area of 9.5 m^2 [96,97].

On the contrary, Golić et al. [98] specify thoroughly a set of urban planning criteria and a detailed evaluation system for SWH building potential calculation for residential building retrofit purposes. Izquierdo et al. [99] who deal with the estimation of the technical potential of roof-integrated PV systems, use available data such as land uses and population and building densities combined with GIS maps so as to compute available roof-top areas based on specific coefficients associated with void fractions within a building block, shadow effects and roof elements' configuration, for which, however, no error can be estimated as they are obtained by in situ audits and measurements. Similarly, Ordóñez et al. [100] determine successfully the solar energy potential in Andalusia for PV systems installed on residential rooftops using digital maps obtained from Google Earth TM and examining in depth a typical sample of buildings. Finally, for urban solar energy potential estimation, Arboit et al. [101] define indicators accounting for solar shading within a sample of city blocks and then assure their representativeness by accounting for the number of units with identical features (shape and orientation) on available city maps. Last but not least, several efficient methods are also published in the past [102–105], which are mainly based on 3D city models combined with GIS implementation or solar radiation or lighting software applications, albeit this kind of approaches cannot be successfully applied when the objective is the solar potential estimation for multiple cities and urban areas in a certain geographical region.

3.1.1. Solar potential on roof-top areas

It is easily derived that most of the past researches do not involve thorough quantifications of actual suitable areas for solar systems on buildings, and especially for roof surfaces, for which no direct data and information exist and they can only be defined in accurate way through individual in situ surveys, which are undoubtedly expensive and time-consuming. Several authors, however, by using aerial roof element image recognition, GIS maps and CORINE land use data, estimate suitable solar roof-top areas for municipality territories or even for entire country regions, initiating from the examination of a representative sample of existing buildings [99,100,106]. Within the same context, our methodological approach for the approximation of solar roof-top areas in urban regions is developed as follows.

At first we use combined aerial images with GIS maps (Fig. 3) which allow us to recognize roof objects (e.g. elevator shaft, chimneys, HVAC, parapet etc) as well as penthouses in order to compute the architectural available (A_a) roof-top areas for PV and SWH technologies by subtracting these objects' areas from the gross built-up areas. This task is carried out by taking advantage of useful measurement tools provided by available GIS and aerial maps (Fig. 4). Of course, the recognition of roof elements cannot be avoided, as it is an unpredictable parameter which varies among buildings, therefore needs aerial image definition at least for an adequate sample which should be representative of the under study building typologies, in our case MF-buildings. Then

Fig. 3. Aerial image (left) and the respective GIS image (right) of a typical building block, where roof elements, such as stairwell and elevator shaft are easily recognized and defined.

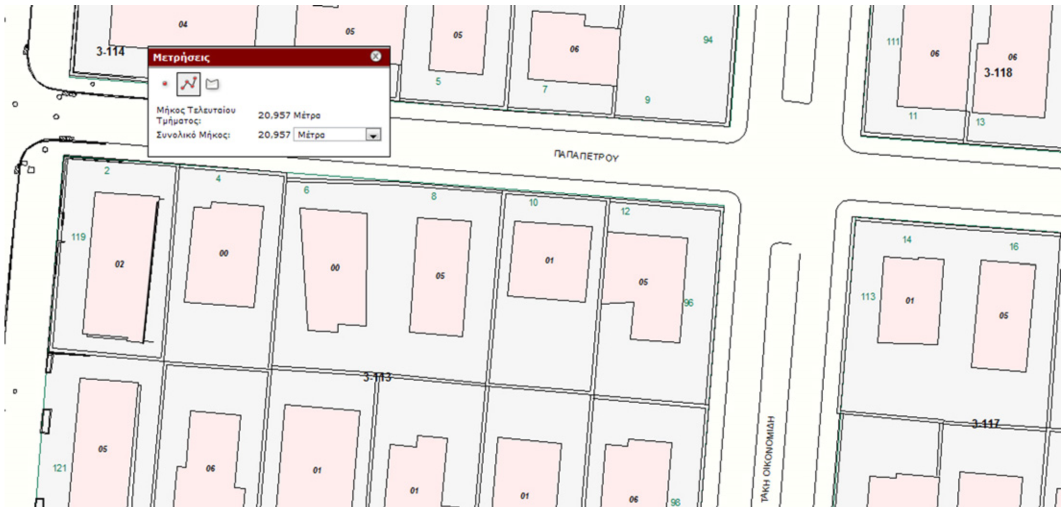

Fig. 4. The internal window provides the user with surface area and perimeter length measurement tools.

the results can be scaled in a whole urban region. On the contrary, the gross built-up areas are directly obtained from GIS maps, as they contain roof print shapefiles with the outline of all buildings.

Secondly, when it comes to the estimation of the shaded areas which will result in the overall solar architecturally suitable areas (S_a) and solar utilization factor (SU_f) per built area or capita, the common criterion of optimal operation of solar systems for at least a four hour interval during winter solstice is implemented. It should be noted that this criterion is stricter for PV systems than for SWH systems, due to the inevitable higher operational sensitivity of the former when the installation field is shaded. Within our approach, simulation runs with shading calculation software can be completely avoided and this is key element of our research in this section. Our main goal is to develop an empirical "shading effect" rule for MF-building typologies, which will estimate shading factor, setting simply the following roof configuration parameters: the placement of staircase, elevator shaft and chimneys; the orientation, the perimeter and the shape (rectangular, angular or polymorphic) of the roof; and the ratio of roof's near south facing side to east/west facing side and the fraction of roof perimeter to gross area. Last but not least, the absolute location of each building is also taken into consideration, providing information whether it is detached or attached to higher neighboring buildings on its near south, well orientated facing side. In this case, we use available GIS information about the number of floors, namely the total height, of each building. All above parameters can be directly exported with the aid of GIS maps, given that roof object-image recognition is completed, and thus the time needed for solar potential computation including shading effects can be successfully decreased to a great extent. Details about the development and the validation process of the presented "shading effect" rule are not involved within the scope of this paper [107].

Apparently, the core of the presented methodology includes an efficient classification of typical roofs of MF-buildings, determining all above construction parameters which influence total solar potential on built roof areas. Finally, inclined roofs are not examined in this work as they regard a limited fraction of existing roofs in building stock in Greece and can be more straightforwardly classified and elaborated compared to flat roofs, as it is also argued by Hachem et al. [108].

3.1.2. Energy outputs and demands

The estimation of solar utilization potential in an urban area from the beginning aims at developing a "solar energy planning" scheme [54], which will allow the energy policy decision makers implement efficient measures for further diffusion of solar systems in building stock, as well as optimize the design of newly constructed urban areas to achieve net zero energy consumptions. Still, in order to accomplish this objective, apart from the solar suitable areas, information about the overall energy and power potential of solar resources is needed. Moreover, the degree in which residential baseline energy demands are eventually covered must be determined. For that purpose four MF-building typologies (Table 1) were simulated with EnergyPlus software and examined as for their energy demands and consumptions [42]. The exported results facilitate the evaluation of the total energy demands for electric appliances, lighting systems and DHW for the whole urban area, by a simple recognition of these typologies in GIS maps. All other prerequisite data for the energy calculations, related to the total built area, exterior surface area, number of storeys and population density per building, are already included in the database of GIS, thus compensating for individual audits.

As far as PV systems are concerned, the analysis is carried out initially, following, by and large, a similar approach to Ordóñez's et al. [100]. In other words, two different installation formulations, namely two overall installation coefficients for PV systems on roofs are assumed, which are based on two roof orientation scenarios (south or southeast/southwest) and the criterion of nil mutual shadowing between parallel PV series at midday during winter solstice, for annually optimal inclination angle and common dimensions assumed for PV panels. Thereafter, the solar suitable areas are multiplied by a hypothetical mean efficiency factor for multi or mono-crystalline silicon PV panels, which are most readily available in current market, so as to account for the PV potential peak capacity (in kW) per building. Afterwards, by using the well-known online utility tool of PVGIS [109] an average energy output per kWp can easily be exported, taking into consideration set system losses due to wiring, inverter, cell temperature increase and PV panel mismatch. Finally, the results are compared to typical electricity energy demands.

When it comes to the SWH systems, the calculation process until the average efficiency consideration is absolutely familiar to PV systems' approach, with one major difference apparently involved which concerns the higher inclination angle (winter's optimal) of SWH panels. Furthermore, the solar DHW fraction is computed using the widely used *f*-Chart method [110]. The input data for the *f*-Chart method are the monthly values of incident solar radiation, ambient temperature, water mains temperature and DHW loads,

variables all of which are derived from the Technical Directives of Greek Regulation of Energy Efficiency of buildings.

3.2. Building's envelope

The building's envelope is without doubt the most crucial factor affecting building's energy behavior. Therefore, in current work, primary objective related to the building's envelope is the computation of the average vertical and horizontal surfaces of the built environment based on GIS tools. The proposed procedure allows the determination of retrofit measures potential, as well as the relevant costs produced. More specifically, the available vertical surfaces are defined according to the year of construction and the construction typology; in other words in correspondence with building's position (detached or attached to neighboring buildings), the exterior vertical surfaces are approximated. Similarly, horizontal surfaces are calculated, considering available roof and pilotis areas. Following the exterior vertical and horizontal surface areas, the total envelope's surface area of the buildings under study is at last accounted for. The outcome of this approach can significantly influence energy policy making, as at first it provides vital information about the mean amount of the insulation materials needed for buildings' energy refurbishment as well as aids the selection of most efficient type of green roof system and the specification of appropriate shading technologies and other envelope related saving energy techniques. In this context, a holistic approach of retrofit scenarios and the associated subsidy and implementation expenses can be completed combined with an extensive comparison of the estimated energy conservation outputs. Table 2 shows the main objectives of this study and the main aspects of the evaluation criteria with respect to buildings' envelope.

3.2.1. Green roofs

The existence of green areas in the urban space is beyond doubt of great importance. Green is valuable for the atmosphere, whilst it offers cooling comfort during summer, shelter during rainfalls and last but not least improves our cities' attractiveness. In this framework, an important aspect is the availability of free space for green plant implementation in built-up areas. Namely, Yang et al. argue that, while vegetation can control air pollution, it is often difficult to plant trees in dense cities due to the lack of free spaces [111]. Alternatively, they propose green roofs as a viable solution to this problem and support this perspective with findings of their study; namely, the atmosphere pollutants could reach the amount of 2046.89 metric tons if all rooftops in Chicago were covered with intensive green roofs. Moreover, the costs of such venture could be justified in the future considering the environmental benefits [111]. Similarly, as regards Greek cities, urban density could stifle refurbishment potential by means of green roofs installation. However, above ground level, at the level of rooftops, an extreme potential for green roofs installation is revealed. By consequence, green roofs are considered a short and less expensive way of incorporating green into the cities, rather than demolishing entire building blocks in order to create larger free green areas. Furthermore, the fact that Greek MF-buildings are equipped with balconies has more or less deadened the vital role of rooftops.

Besides architectural perspectives that are not as important as other environmental aspects, green roofs are favored for various reasons such as air pollution removal [111–113], urban reconciliation ecology [114], sound absorption [115,116], reduced energy consumption in buildings [117–121], rainwater runoff solutions [122–124] and their overall life cycle performance [125].

Hence, as in our case any refurbishment interventions do not only concern the building unit but also the city as a whole, the implementation of green roofs is inevitably a crucial saving energy option. Finally, based on the buildings' age and the corresponding statics of the construction, conclusions can be easily drawn associated with the type of the green roof that can be applied.

3.2.2. Opaque surfaces and openings

Practicing thermal insulation measures is not a new retrofit approach, though popular till today. In particular, the UK Department of the Environment endorsed the 'Homes Insulation

Table 2
The scope of the study regarding the buildings' envelope based on various data sources and evaluation criteria.

Result	Evaluation parameters	Data source	Applied method	Depiction format
A/V ratio	Buildings' volume	GIS maps	(Building's height [number of floors $\times$ 3 m] + ground floor [height 4.5 m]) $\times$ building's surface	Table
	Construction system (attached or detached buildings)	GIS maps and El. Stat. data	Vertical building's surfaces (building's width $\times$ height)	
	Pilotis or ground floor	GIS maps and El. Stat. data	Horizontal building's surfaces (horizontal roofs and pilotis floors)	
Mean A/V ratio	As described above			Table
Mean buildings' height	As described above			Table
Mean energy consumption per building class	Correlation of the sample with the typical buildings	[42]	According to the buildings': typology—year of construction	Table and map
CO_2 emissions	Correlation of the sample with the typical buildings	[42]	According to the buildings': typology—year of construction	Table and map
Mean energy conservation per building class	Correlation of the sample with the typical buildings (after the implementation of typical retrofit measures)	[42]	According to the buildings': typology—year of construction	Table and map
Available vertical and horizontal surfaces for retrofit measures	for: green roofs, thermal insulation, openings, PCMs and cool materials	[42]	According to the buildings': typology—year of construction	Table and map

Scheme' by promoting improved energy behaviors of loft through thermal insulation technologies [126]. Moreover, energy consumption can be highly reduced by the implementation of thermal insulation materials [127]. The exact amount of energy consumption reduction varies according to the optimum thickness of the material that is determined based on the construction characteristics of each building and the respective climatic conditions. Furthermore, Anastaselos et al. studied various thermal insulation solutions based on their environmental impact, their initial cost, as well as the expected energy savings for a typical MF-building in Greece [128]. In order to evaluate the effect of this kind of measures and extrapolate the respective energy conservation results to city scale, several base case scenarios were examined, as referred in previous sections, performing insitu measurements and completing dynamic energy simulations with the aid of Energy Plus software [42]. Similarly, Shi used EnergyPlus for the computation of the heat transfer loads in order to define the optimum thermal insulation widths [129]. In this line of thought, thermal insulation, Phase Change Materials (PCMs) as well as cool materials can be studied by means of minimizing heat island effect, improving interior thermal comfort conditions [130] and reducing cooling and thermal loads of buildings [131].

More specifically, based on Table 3, the available vertical and horizontal surfaces should be set so as to decide for respective energy interventions. At this point, the estimation of the exposed opaque vertical surfaces of the buildings, besides the width and the height of the facades and the openings to wall ratio is inevitably needed. This information, however, derives from typical buildings. Hence, the calculations are based on the following equation:

$$S_{va} = S_v - S_o \tag{1}$$

where S_{nv} is the net vertical surface area (opaque building's surface), S_v is the total vertical surface area, S_o is the openings' surface, The S_o values for four typical buildings are depicted in Table 3.

With respect to the buildings' openings the approximation of their total surface area, is a complex process, especially, when it comes to GIS data analysis. Due to that reason, information associated with the exact openings' surface is prerequisite in order to be imported to the GIS data base for each building. For that purpose, two methods can be adopted; the first one concerns thorough in situ measurements and detailed inspection of the buildings' facades. Afterwards, the obtained measured data can provide a 3D GIS database, which will reflect the existing façade configuration of buildings. It becomes obvious that this procedure concerns a time-consuming and strict task, which is not, whatsoever, related to the character of the proposed flexible methodology.

Therefore, for reasons of brevity a second approach is efficiently implemented; after the correlation of the GIS buildings with the already elaborated typical building sample, all information is easily exported based on their analysis, described in the previous section. This method is undoubtedly not as accurate as an in situ detailed survey, but it does lead to representative outcomes regarding retrofit policy making decisions.

Table 3
Window to wall ratio of the typical buildings.

	MF1	MF2	MF3	MF4
Window to wall ratio [%]	24.42	21.81	22.41	13.37

3.2.3. Built form and A/V ratio

Apart from the ventilation losses, building's energy losses also occur through its envelope that is exposed to the environment. It is already known that the greater the external surface areas are the higher the energy losses that take place. Apparently, the A/V ratio, which was introduced for that purpose describing the fraction of the total building's envelope surface A to its conditioned volume V, is the best indicator that correlates s the structure and form of a building with its energetic behavioral profile [132].

In that case, building form eventually does affect energy consumption; Wright argues that the operation profile of households determines in higher degree the overall energy behavior of the building than its built form does. However, he also states that larger houses tend to be less energy efficient [133]. Thus, assuming identical operation profiles for two different forms of buildings, the one with larger A/V ratio, in other words the less compact one, will consume more energy, according to its orientation, the climatic conditions and the surrounding built environment.

Moreover, Ratti et al. study the relation between urban texture also based on the surface-to-volume ratio, in order to evaluate its impact on the buildings' energy performance whilst argue that the buildings should always be examined as a part of a built environment and not as "self-defined entities" [134]. Within that scheme, indenting to plan large scale intervention measures for the existing building stock, residential or not, on a national basis, needs for a safe study of the urban texture and the urban typology to be carried out. A typical example is the design of retrospective thermal insulation implementation, depending on the urban buildings' envelope and the structure of the built environment. In that sense, our methodology approach aims at integrating an analysis of the stock as regards, detachment, attachment, orientation and height of the buildings, in order to avoid inaccuracies concerning the overall energy performance of the city.

Given the fact that Greek cities are extremely dense and compact [41], the case of row-system built environment, characterizing especially Greek city centers, can have positive outcome on the overall energy performance of the buildings, from a heating loads point of view. In particular, Greek cities are typical for their MF-buildings, constructed in row-system [41], a parameter, which determines certain A/V ratios as long as it influences energy performance of the buildings under study.

In Table 4 the maximum allowed values regarding the U_m of the building's envelope are depicted, based on the specifications of the Greek Regulation of Energy Efficiency of Buildings.

3.3. Overall energy balance

The estimation of the energy behavior of urban buildings is a complicated and challenging objective. There are numerous examples of fulfilled research efforts each referred to various assessment tools, based on available data since the early 70s

Table 4
Maximum allowed mean thermal transmittance of the building's envelope U_m according to the A/V ratio and the climatic zone of Greece [W/m^{2}K] [135].

A/V ratio [m^{-1}]	Climatic Zone A	Climatic Zone B	Climatic Zone C	Climatic Zone D
≤ 0.2	1.26	1.14	1.05	0.96
0.3	1.20	1.09	1.00	0.92
0.4	1.15	1.03	0.95	0.87
0.5	1.09	0.98	0.90	0.83
0.6	1.03	0.93	0.86	0.78
0.7	0.98	0.88	0.81	0.73
0.8	0.92	0.83	0.76	0.69
0.9	0.86	0.78	0.71	0.64
≥ 1.0	0.81	0.73	0.66	0.60

[44,136–145]. With respect to the residential building sector, the determination of the energy performance becomes even harder to comprehend due to the various occupancy profiles and the diverse buildings' typologies, factors that are well acknowledged by several researchers [146].

The scope of this paper is to provide the proper assessment methodological tool for the energy behavior of building blocks in urban regions. Given the fact that the inhabitant concentration in Greek cities is extremely high, general data regarding the energy consumption cannot contribute to a safe adoption of sustainable energy policy measures. This GIS-based approach aims at specifying the urban energy behavior profile and consequently assisting researchers and public bodies to plan energy refurbishment measures in a more appropriate manner. Hence, taking into consideration the typical MF-buildings, the energy performance of the corresponding building classes is initially defined. Thereafter, the overall energy behavior of the residential stock is ultimately evaluated so that respective retrofit scenarios can be safely proposed and designed.

4. Case study

The urban fabric of Thessaloniki was chosen as a case study area. Thessaloniki is the second largest city of the country in Northern Greece and enumerates 1,100,000 inhabitants. Due to its geographical position and its commercial port, Thessaloniki is Greece's second major economic, industrial, commercial and political center, as well as a major transportation hub of southeastern Europe and the Balkan area with a very long history. Namely, the city was founded around 315 B.C. by the King Cassander of Macedonia and named after his wife Thessalonike, a half-sister of Alexander the Great. After the era of the Macedonian kingdom Thessaloniki became a city of the Roman Republic in 168 B.C. and in 379 the capital of the new Prefecture of Illyricum. The byzantine period was followed by the long ottoman rule during the period 1432–1912 [147].

With respect to its architectural influences, it is important to notice that the historic center was completely destroyed in 1917 due to a disastrous fire. Thomas Mawson and Ernest Hebrard undertook its redesign, based on the city's Byzantine historical influences. Despite the fact that their reconstruction proposals were not fully implemented, they influenced numerous buildings' and urban planning decisions throughout the 20th century, regardless of the inevitable adaptations in order to adjust to the population explosion of the last 50 years. Hence, architecture in Thessaloniki is the direct result of its long history and the various architectural historical origins; beyond the ancient Greek monuments, several notable Byzantine monuments, as well as numerous Ottoman and Sephardic Jewish structures adorn the center of the city [147].

Furthermore, apart from the historic monuments in Thessaloniki, 80% of the buildings have an absolute residential use, whilst 90% of the buildings with mixed use refer to MF-buildings with mainly household usage combined with shops or offices on the ground floors and practices in upper floors. Thus, the majority of Greek urban buildings are mainly residential [41]. Within this framework the focus of this case study area lays, unavoidably, on residential MF-buildings when it comes to building stock analysis.

Based on the methodology approach proposed by Theodoridou and Papadopoulos [41], after the determination and energy efficiency study of typical buildings, the next target to reach is to connect the acquired data with the overall urban environment. For that purpose, digital maps of the two largest urban districts of Thessaloniki were analyzed using the Arc-GIS program. These maps contained data regarding building units, plot areas and public spaces (streets, pedestrians, parks, etc.). For each building units and blocks, data concerning the land use, date of construction, built area and heights were available. Therefore, the analysis focused on all these aspects, which apparently affect the energy performance of Greek MF-Buildings.

4.1. Available data

Data availability combined with accurate digitized GIS urban maps is undoubtedly the most crucial parameter to apply efficiently the presented methodology for building's energy behavior assessment and RES potential examination in urban areas. In our case study all the elaborations, developed in GIS environment relied on, spatial explicit large scale maps of the building footprints and city blocks for the two largest municipalities of the region of Thessaloniki were retrieved, namely the Municipality of Thessaloniki [148] and the Municipality of Kalamaria [149].

To assess reliability of the maps, we overlaid them with large scale orthoimagery (20 cm spatial resolution) acquired during 2007 over Greece, available on a Web Mapping Service (WMS) [150]. Whilst the city plan of Kalamaria Municipality was found to be very reliable in terms of spatial accuracy and information content, in Thessaloniki's case faults in building footprints digitization were noted. The spatial database of the city plan maps were enriched with census information acquired by National Statistical Authority related to the land use, the height and the construction systems available mostly on building unit level for the Municipality of Kalamaria and on city block level for the Municipality of Thessaloniki.

The ESRI ArcGIS 9.3.1 environment was used at first place for processing and analyzing the urban datasets. The Trimble eCognition 8.0 mainly employed within the framework of the Geographic Object-Based Image Analysis (GEOBIA), a sub-discipline of GISscience [151], was used for building classification in both municipalities (Fig. 5). The recently developed eCognition software exploited so far for segmentation and object-based classification of remote sensing images, is suited and has the potential to be adopted widely by end-users to build landscape level-solutions for environmental and social studies with object based investigation using non-image spatial data [152]. Within eCognition 8.0 classification framework, multiscale representation of environmental phenomena is feasible and discrimination of classes of interest, relies on object values of each individual object (i.e. building, block, city district) operating in the semantic hierarchy based on a large set of features that can be calculated and provide diverse information about its spectral, textural, spatial and contextual properties [153]. Also, classification within eCognition is based on fuzzy sets [154], which are able to incorporate inaccurate measurements, vague class descriptions and imprecise modeling into the analysis approach making it well suited as part of any decision support system [155].

As mentioned above, as a consequence of digitization errors in building footprints map in the case of Thessaloniki municipality, real-world attached buildings within row system, were depicted in the city plan as nearly detached. Therefore, a viable solution for the classification of the buildings was the use of neighborhood-related information of the different footprints.

To generate objects corresponding to building footprints, fine resolution (0.1 m) raster images covering the whole extent of the municipalities were generated with ArcGIS Spatial Analyst. In the next step, the image was imported within the eCognition software along with the city's buildings and blocks vector datasets for segmenting the image. Following, the bi-level segmentation, objects at the lower, fine scale level were classified based on the land use values included in the attribute table of the vector

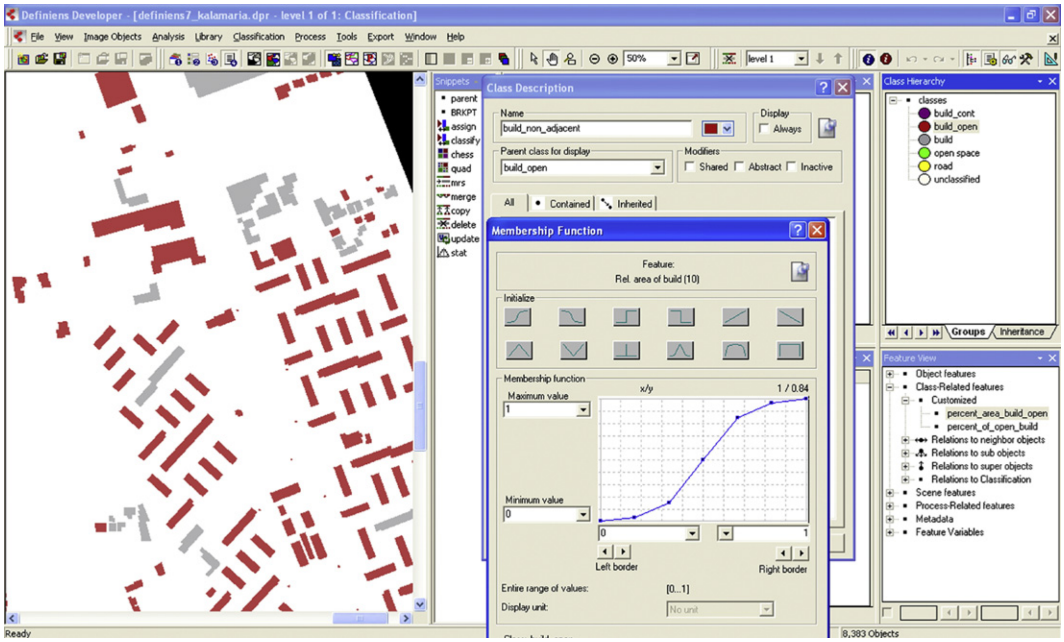

Fig. 5. The eCognition software tool.

Table 5
Averaged unavailable roof element areas as a fraction of gross roof (G_a) area, for the examined sample of MF-buildings [107].

Roof unavailable areas	Staircase/elevator shaft and chimney area (St_{af}) (%)	Perimeter safety area (0.5 m wide across roof perimeter) (Saf_{af}) (%)	Penthouse terrace area (considered only if exists) (Pe_{af}) (%)	Rest of roof element areas: storage rooms; perimeter parapet (RE_{af}) (%)
Mean values	15.0	24.1	5.1	7.1

dataset (buildings, open spaces, roads). In the next step, fuzzy realization of the class-related object features (namely distance to buildings, relative area of buildings, and number of buildings within a certain distance) were used to classify buildings. Information of the lower level was transferred to the upper, coarser level of city blocks where each object-block received information from its sub-objects regarding the relative area and number of each class. Finally, the classification results were exported in a vector format to the ArcGIS environment and used in the subsequent modeling approach

Nevertheless, this paper aims ultimately at presenting a methodological approach that was developed to compensate for inadequate statistical and GIS data and last but not least at giving the opportunity for energy policy makers, for first time in Greece, to use GIS systems combined with RES potential estimation, building stock energy behavior evaluation and optimal retrofitting measures analysis for urban regions.

5. Results

5.1. RES implementation

5.1.1. Assumptions and input data

In what concerns PV and SWH, there are two groups of assumptions and input data that are considered initially with respect to the case study urban area of Thessaloniki.

The first group concerns the architectural suitable (A_a) roof areas that are already accurately defined for a representative sample of typical MF-buildings in the urban area of Thessaloniki by applying image-roof object recognition using aerial maps [107]. The derived unavailable surfaces are then averaged and scaled for the whole urban area. The most important results, expressed as a fraction of gross roof (G_a) areas, are depicted in Table 5. At a glance one can notice firstly the average unavailable area fraction which reaches nearly 50% of the gross area and secondly the high area fraction covered by perimeter safety area, which cannot be avoided as it is mandatory for RES roof applications according to current building regulations.

The remaining results exported from the examination of the aforementioned sample are those roof configuration parameters, which concern "shading effect" rule, and influence eventually shaded areas. In particular, the latter are defined when the absolute position for each building is recognized, in order to input the proper shading factor, as if the building is detached or attached to higher neighboring building only on its near southern ("well-orientated") sides. In Table 6 the shading factor as a fraction of architecturally available (A_a) areas is depicted, for four categories of building's position.

The second group of input variables that is needed in order to complete solar potential computations for the selected city of Thessaloniki include the electricity and DHW production by the estimated PV and SWH systems, and the electricity and DHW demands normalized per building area.

As far as PV systems' electricity production is concerned, we take into consideration a mean PV efficiency of 14.0% for typical PV modules as well as other system losses (cables, inverter etc) up to 14.0% too, while PVGIS calculations include temperature and angular reflectance losses according to examined location's climatic conditions. Moreover, roof-top PV panels are considered free-standing with optimal inclination (30°) and south orientation, whereas regarding the roof potential, the actual installed PV

Table 6
Averaged shading factor as a fraction of architecturally available (A_a) areas, according to building's position, for the examined sample of MF-buildings [107].

Building's position	Detached (%)	Attached to one storey higher building* (%)	Attached to two storey higher building* (%)	Attached to at least three storey higher building* (%)
Shading factor (Sh_f)	71.5	91.9	97.2	98.6

* Typical storey height equals to 3 m.

Table 7
Annual electrical consumptions for lighting systems and electrical appliances (kWh/m^2) for the examined sample of MF-buildings [107].

MF-building typology	MF1	MF2	MF3	MF4
Annual electrical consumptions for lighting systems and electrical appliances (kWh/m^2)	38.38	39.98	39.61	42.94

surface is assumed to cover approximately 50% of the computed solar suitable (S_a) roof areas, due to the applied criterion of negligible mutual shading losses between parallel PV series. So, the final PV area is obtained based on the VSA at noon during winter solstice and fixed typical dimensions for PV panels, e.g. 1580×808 mm^2. Finally, the annual electricity consumptions for electric appliances and lighting systems per building area are derived from MF-building simulation results and attributed to the total built urban area according to their typological characteristics, so as to account for the annual solar electricity fraction provided by the computed PV systems (Table 7).

Regarding the SWH systems, the actual installation factor for roof areas follows the same estimation pattern compared to PV systems, although the SWH panels are theoretically installed in 45° inclination angle (optimal for winter), so the required distance to avoid shadow effects between parallel series is inevitably longer. This parameter, unfortunately, leads to a reduced overall roof utilization factor of SWH systems approximately by 7% compared to PV. As for the approximation of the energy loads for DHW and the annual solar DHW solar fraction, the *f*-Chart method is applied. The necessary input data involve monthly incident solar radiation information for fixed inclination and orientation, water mains and ambient temperatures as well as DHW demands per person, for which we especially take into consideration population density per building block, acquired from the GIS database. Climatic and the other prerequisite data are provided by the national Technical Directives [135,156]. Further details are given in Table 8.

Table 8
Monthly ambient and water mains temperatures, DHW demands per person and solar DHW fraction for one person's needs provided by 1 m^2 south facing SWH panel with 45° inclination angle in the region of Thessaloniki [156].

Months	Ambient temperature (°C)	Water mains temperature (°C)	DHW demands per person (kWh/person)	Solar DHW fraction for one person's demands provided by 1 m^2 south facing SWH panel with 45° inclination angle (%)
Jan	5.3	6.5	75.61	63.72
Feb	6.8	7.3	69.27	70.76
Mar	9.8	9.4	72.92	81.40
Apr	14.3	13.2	63.97	99.50
May	19.7	17.6	58.19	114.47
Jun	24.5	21.9	48.84	128.87
Jul	26.8	24.3	46.16	136.23
Aug	26.2	24.6	45.62	135.06
Sept	21.9	22.0	48.67	122.63
Oct	16.3	17.7	58.01	97.42
Nov	11.1	12.7	64.83	73.92
Dec	6.9	8.6	74.36	61.08
Mean values	15.8	15.5	60.54	98.75

Table 9
PV potential capacity on roof-top areas.

	PV capacity (kWp)	Number of buildings	Building stock fraction (%)
Municipality of Thessaloniki	0.0–1.0 (unsuitable roofs)	9076	51.88
	1.0–5.0	7992	45.68
	5.0–10.0	382	2.18
	Over 10.0	44	0.25
	Total	17,494	100.00
Municipality of Kalamaria	0.0–1.0 (unsuitable roofs)	2020	33.74
	1.0–5.0	3864	64.54
	5.0–10.0	103	1.72
	Over 10.0	0	0.00
	Total	5987	100.00

5.1.2. *Solar potential results*

The most significant outcomes regarding solar potential on roof-top areas are formed as follows: initially the estimated PV potential capacity of buildings is presented combined with building stock fractions related to four PV system classes of capacity, namely unsuitable roofs (0.0–1.0 kWp), one phase grid-connected PV systems (1.0–5.0 kWp), three-phase grid-connected PV systems (5.0–10.0 kWp) and PV systems over 10.0 kWp. The latter class refers to PV systems which are not eligible for obtaining current tax-free feed-in tariff (0.55 €/kWh) for grid-connected building applied PV systems, set by a national special PV development program of the Ministry of Environment and Climate Change, as their capacity exceeds the fixed maximum cap of 10 kWp. In current work, all building applied PV systems that are examined, are assumed to be grid-connected in order to be economic profitable, although, the annual solar electricity fraction is estimated as if the PV systems feed MF-buildings' own electricity consumptions for lighting and electrical appliances. In that case, systems over 10 kWp are the most efficient in terms of saving electrical energy and eventually reducing daily peak electrical power.

More specifically, from the following tables (Table 9 and 10) it is easily derived that the majority of systems consider either unsuitable roofs or single-phase systems. In the case of municipality of Thessaloniki over 50% of the available flat roofs are unsuitable, whereas there is a 45.68% which can feed 1–5 kWp into the grid, under only optimal operational standard test

Table 10
Annual solar electricity fraction by roof-top PV systems.

	Annual solar electricity fraction (%)	Number of buildings	Building stock fraction (%)
Municipality of Thessaloniki	0.0–5.0	7970	45.56
	5.0–10.0	7785	44.50
	10.0–15.0	930	5.32
	Over 15.0	809	4.62
	Total	17,494	100.00
Municipality of Kalamaria	0.0–5.0	1000	16.70
	5.0–10.0	2850	47.60
	10.0–15.0	1339	22.37
	Over 15.0	798	13.33
	Total	5987	100.00

Table 11
Annual CO_2 emissions reduction by PV potential roof-top systems.

	Values	PV capacity (kWp)	Annual solar electricity production (kWh)	Annual CO_2 emissions reduction (0.989 kg CO_2/kWh of primary electrical energy)
Municipality of Thessaloniki	Average	1.35	1,950.00	5,592.80
	Maximum	14.53	20,935.00	60,043.67
	Total	23,685.00	34,107,448.00	97,823,571.61
Municipality of Kalamaria	Average	1.45	2,093.48	6,004.31
	Maximum	9.57	13,784.10	39,534.19
	Total	8,703.93	12,533,657.89	35,947,784.19

conditions. Moreover, there is approximately only a 2.5% which refers to three-phase PV systems, indicating that the predominant row system in building blocks as well as the miscellaneous heights of adjacent buildings in this specific urban area mitigates significantly solar architecturally suitable top-roof areas. This fact leads, additionally, to a limited annual solar electricity fraction ($<5\%$) for the largest proportion of building stock (45.56%), given that the shading problems are more intense, the potential capacity is low whilst there are large built areas per building (higher buildings), meaning high overall electrical consumptions per building. On the contrary, when it comes to the municipality of Kalamaria, where the built area per building is reduced (and apparently the total electrical demands per building) combined with the predominant detached construction system that favours for greater solar suitability of flat roofs, both the higher fraction of building stock possess more one-phase PV systems (64.54%) than unsuitable roofs (33.74%) and respectively the annual solar electricity fraction that is over 10%, is provided at least by the 35.7% of the examined buildings. The same variable does not exceed 9.94% in municipality of Thessaloniki.

A better aspect of the annual solar electricity fraction is obtained in the following figure (Fig. 6), where, in the case of Thessaloniki, the red colored buildings (those with low solar fraction) cover larger part of the examined area than in Kalamaria, with the green ones (with fraction over 10%) being remarkably limited. On the contrary in the municipality of Kalamaria the green MF-buildings prevail against the red ones, while the most widespread type of buildings are those with 5–10% annual solar electricity fraction both in two cities.

Last but not least, as far as PV system potential is concerned, in Table 11 some interesting outcomes are shown; at first, it is noticeable that the sum of the PV capacity in Thessaloniki reaches 23.0 MWp, whereas in Kalamaria only 8.7 MWp, due to the less amount of existing buildings and ultimately the aggregated CO_2 emissions reduction provided by PV potential roof-top systems accounts for 133,771.355 t CO_2 on an annual basis.

In similar pattern with the PV potential, the results about SWH systems show the lower annual solar DHW fraction that is estimated for the municipality of Thessaloniki compared to Kalamaria. In further detail, the 81.0% of the building stock in the former municipality covers 5.0–60.0% of the DHW demands per building (Table 12). The 60% minimum solar fraction threshold, is set by the national Regulation of Energy Efficiency of Buildings as a standard that newly constructed buildings have to fulfill so as to be completely authorized by Urban Planning Authority. Within that context, it is apparently concluded that there is a 10.0% of existing buildings (the 7.67% is represented by SWH systems computed in Kalamaria) that fulfill this obligation.

In general, the potential outcome is greater in Kalamaria than in Thessaloniki (Fig. 7), for similar reasons described above for PV systems, although the total annual CO_2 emissions reduction (Table 13) in Thessaloniki reaches 285,351.754 t CO_2 and in Kalamaria only 108,702.725 t CO_2, taking for granted that the primary energy is electricity. Instead, when the DHW is provided by fuel oil boilers, the aforementioned levels of savings CO_2 emissions are reduced by 90%, and this gets worse if the conventional heating water systems become even more environmental friendly.

5.2. Overall energy balance

5.2.1. Assumptions and input data

As mentioned in previous sections, four typical buildings were thoroughly analyzed in terms of their energy performance, as both real energy consumption data were gathered, whilst the heating energy and cooling consumptions were also exported by Energy Plus simulation software. Further detailed information about the construction and operational characteristics of the examined buildings is given by Theodoridou et al. [42].

For the computation of the annual CO_2 emissions the final energy consumptions for heating, cooling, DHW, lighting and electrical appliances are aggregated based on the kind of primary energy consumed (electricity, diesel oil or natural gas in our case). Then, based on the primary energy factors set by the Regulation of Energy Performance of Buildings (KENAK) and the respective CO_2 emission coefficients (Table 14), the total CO_2 impact of each building is finally estimated.

5.2.2. General results

Based on the main features of the aforementioned typical buildings, a compatibility test took place, in order to match the buildings of the GIS sample to the typical ones. The comparison referred to the building form (approximate height, A/V ratio, detachment or attachment to neighboring buildings), year of construction and existence of Pilotis floor. In Fig. 8 the three categories of construction typologies under study are being depicted. Thus, apart from Class B, Classes C and D are being sub-divided in further categories in order to ensure the link between the maps and the energy behavior characteristics of the sample.

With respect to the buildings' energy behavior, according to their typology, the annual final energy consumption is being depicted in Table 15.

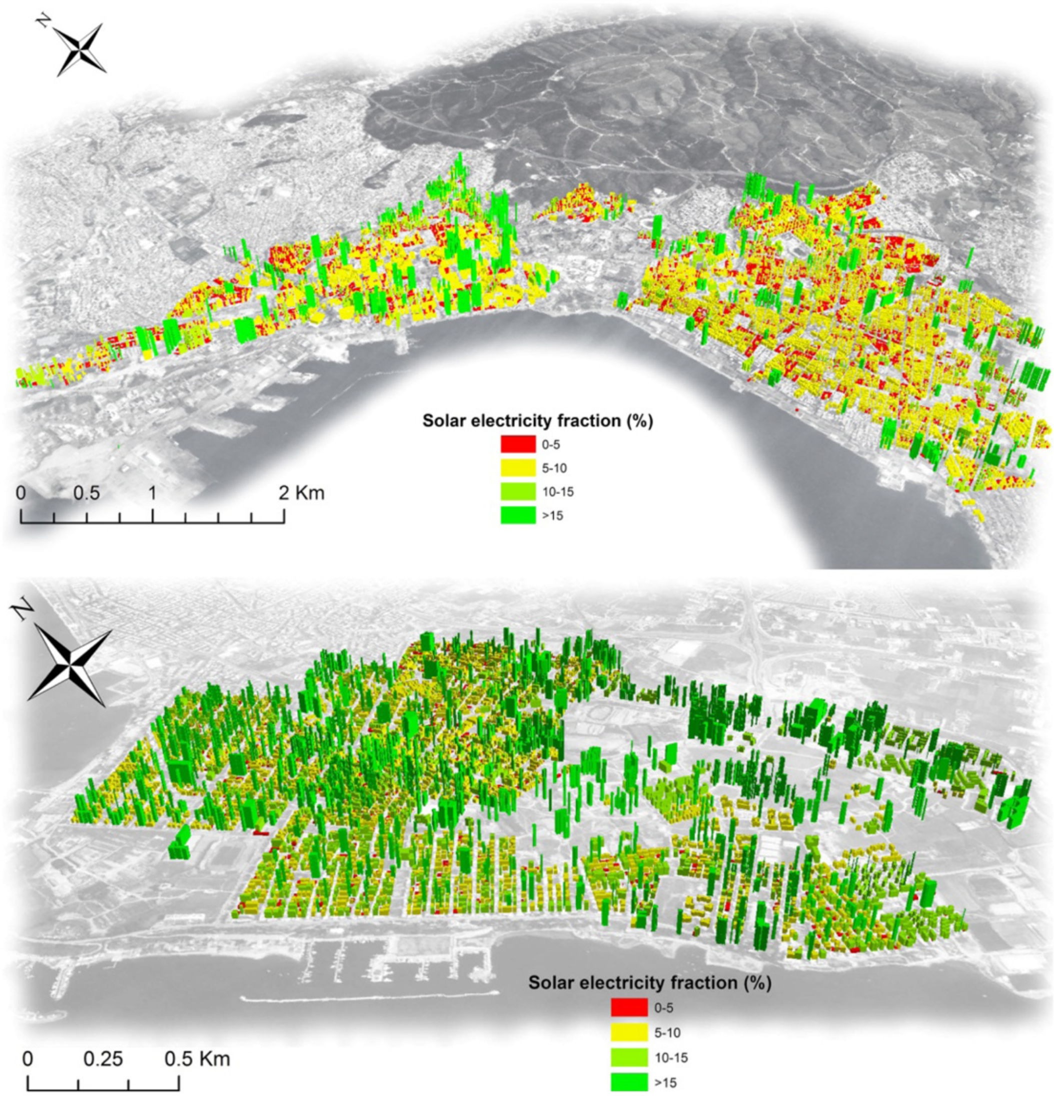

Fig. 6. Annual solar electricity fraction by roof-top PV systems depicted in 3d GIS map of municipalities of Thessaloniki (upper image) and Kalamaria (lower image). *Note*: the heights of the buildings represent the level of the depicted values of solar electricity fraction rather than the actual height of the buildings.

Table 12
Annual solar DHW fraction by roof-top SWH systems.

	Annual solar DHW fraction (%)	Number of buildings	Building stock fraction (%)
Municipality of Thessaloniki	0.0–5.0 (unsuitable roofs)	2915	16.66
	5.0–60.0	14,168	80.99
	Over 60.0% (minimum allowed threshold for newly constructed buildings)	411	2.35
	Total	17,494	100.00
Municipality of Kalamaria	0.0–5.0 (unsuitable roofs)	408	6.81
	5.0–60.0	5120	85.52
	Over 60.0% (minimum allowed threshold for newly constructed buildings)	459	7.67
	Total	5987	100.00

It is important to note that the aforementioned final energy consumptions include the energy consumptions for heating, cooling, DHW, lighting and electric appliances.

As shown in Table 16 83.53% of the sample represents buildings with residential use, whether an absolute or a mixed one, indicating an obvious consistence with relevant studies concerning the elaboration of national statistical data [157]. In this line of thought, the design of retrofitting measures should be consistent with the energy characteristics of the residential building typology. In addition, the majority of the buildings in the Municipality of Thessaloniki, especially those constructed before 1980 (Class B), do not have a Pilotis floor.

Similarly for the Municipality of Kalamaria the results are presented in Table 17. Hence, 93.3% of the studied sample refers to residential use, whilst the percentage of buildings with Pilotis floors rises. Unlike the results concerning the Municipality of Thessaloniki, the majority of the buildings are constructed during 1960–1990. Therefore, Class C becomes more important, similarly to Class D, which now represents 17% of the sample. Moreover, for the case of Kalamaria, the majority of the detached buildings are referring to semi-attachment system (attached to one building). Thus, several MF-buildings of the sample have been constructed in pairs.

With respect to various typological features, the buildings of each sample are being linked to the 4 proposed constructions and their sub-categories. Tables 18 and 19 show the correlation of the

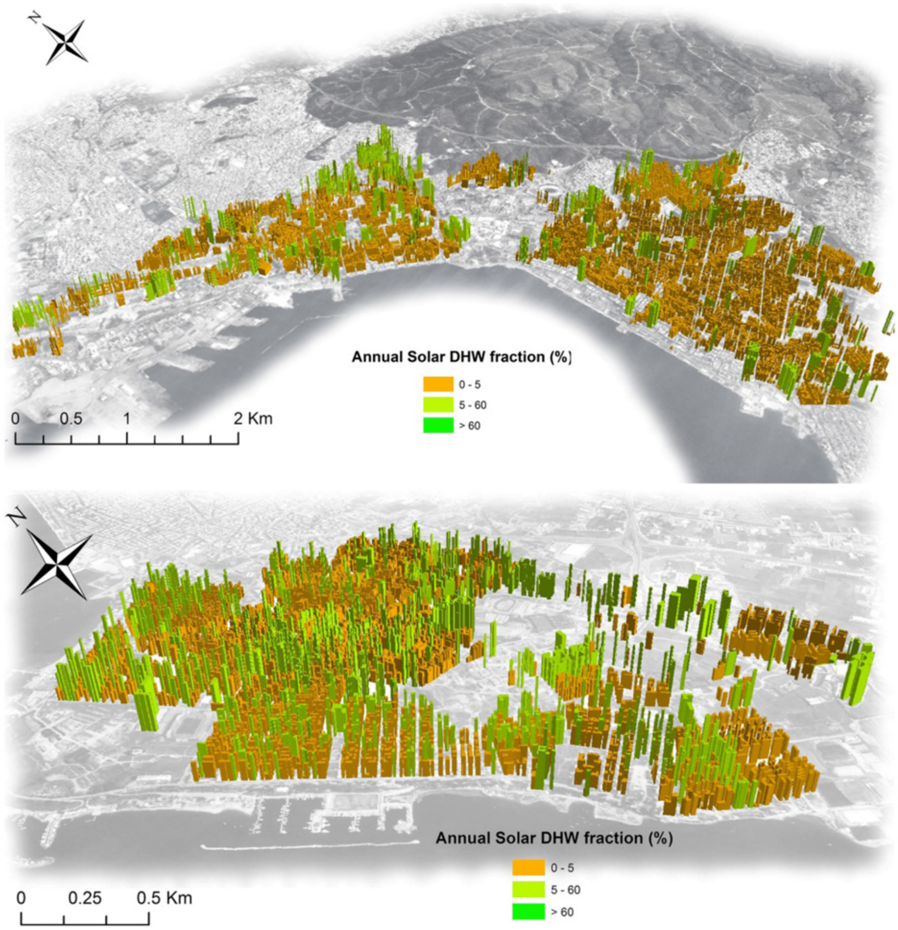

Fig. 7. Annual solar DHW fraction by roof-top SWH systems depicted in 3d GIS maps of municipalities of Thessaloniki (upper image) and Kalamaria (lower image). *Note*: the heights of the buildings represent the level of the depicted values of solar DHW fraction rather than the actual height of the buildings.

Table 13
Annual CO_2 emissions reduction by SWH potential roof-top systems.

	Values	Annual solar DWH production (kWh)	Annual CO_2 emissions reduction (0.989 kg CO_2/kWh of primary electrical energy)	Annual CO_2 emissions reduction (0.264 kg CO_2/kWh of primary fuel oil energy)
Mun. of Thessaloniki	Average	5687	16,310.88	1,651.50
	Maximum	61,069	175,152.00	17,734.44
	Total	99,491,564	285,351,754.71	28,892,350.19
Mun. of Kalamaria	Average	6330	18,155.07	1,838.23
	Maximum	40,208	115,320.56	11676.40
	Total	37,900,605	108,702,725.20	11,006,335.69

sample for the Municipality of Thessaloniki and Kalamaria respectively.

It becomes evident, that the majority of the residential building typology for the city center of Thessaloniki can be safely linked to the typological features of buildings MF1 and MF2 as suggested by Theodoridou et al. [42]. Furthermore, with respect to the energy behavior, partly attached buildings in this case, mainly refer to corner buildings, with a calculated energy consumption increase of only of 3%. With respect to the area of Kalamaria the majority of the buildings are represented by MF2 and MF3.

Overall, the GIS analysis demonstrates that the typical buildings presented by Theodoridou et al. [42] are sufficiently depicting the typological structure of the greater urban area of Thessaloniki. More specifically, buildings MF1 and MF2 are characteristic for the part of the city center, whilst buildings MF3 and MF4 are representative for the urban area of the Municipality of Kalamaria, which was developed rather lately. In this line of thought, the

Table 14
Primary energy factors and respective CO_2 emissions coefficients for Greece.

Source energy	Primary energy factor	CO_2 emissions factor ($kgCO_2$/kWh)
Natural gas	1.05	0.196
Heating oil	1.10	0.264
Electrical energy	2.90	0.989
Liquefied petroleum gas (LPG)	1.05	0.238
Biomass	1.00	–
District heating	0.70	0.347

respective primary energy consumption for each building typology has been calculated and the relevant CO_2 emissions are being depicted in Figs. 9 and 10 for the two study areas.

The most important conclusion drawn from Figs. 9 and 10 is that both study areas figure rather high emissions with respect to the buildings' energy performance. Thus, although the percentage of buildings constructed before the implementation of the first Thermal Insulation Regulation (1980) in Municipality of Kalamaria is only 44%, the emissions are rather high, on similar level with the Municipality of Thessaloniki, where 86.43% of the buildings is constructed before 1980.

5.3. Building's envelope

5.3.1. Green roofs

For the calculation of the available roofs area, the same procedure as for the RES implementation was followed, without the corrections due to shading. Hence, the perimeter of each building leads us to the total rooftop area, from which the percentage of the staircases is being extracted. Namely, approximately 4,772,323 m^2 of available roof areas were calculated according to our GIS maps for the case study area of the city of Thessaloniki.

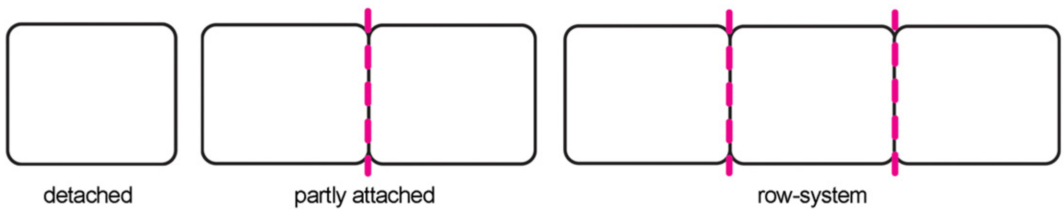

Fig. 8. The three types of construction under study.

Table 15
Annual final energy consumption for with the typical constructions.

Class	Class B			Class C			Class D		
Code	MF1	MF1_p.att	MF2	MF3	MF3_p.att	MF3_de	MF4	MF4_p.att	MF4_r.sys
Status	Row-system	Partly attached	Detached	Row-system	Partly attached	Detached	Detached	Partly attached	Row-system
Final energy consumption [kWh/m^2]	102.07	99.01	166.22	123.56	156.28	167.08	143.14	133.62	128.36

Table 16
Year of construction for the residential buildings' sample in the Municipality of Thessaloniki.

Year of construction [%]				Pilotis [%]	Absolute use—residential [%]	Mixed use—main use residential [%]	Mixed use—secondary use residential [%]
Till 1960	1960–1980	1980–1990	1990–today				
20.05	53.29	16.80	9.61	10.22	37.81	45.72	1.31

Table 17
Year of construction for the residential buildings' sample in the Municipality of Kalamaria.

Year of construction [%]				Pilotis [%]	Absolute use—residential [%]	Mixed use—main use residential [%]	Mixed use—secondary use residential [%]
Till 1960	1960–1980	1980–1990	1990–today				
9.15	37.98	34.32	17.22	41.83	64.77	28.53	0.65

Table 18
Residential buildings of the sample linked to typical buildings (Municipality of Thessaloniki).

MF1	MF1_p.att	MF2	MF3	MF3_p.att	MF3_de	MF4	MF4_r.sys	MF4_p.att.
21.28%	11.13%	20.88%	5.83%	5.77%	5.20%	4.19%	3.60%	1.82%

Table 19
Residential buildings of the sample linked to typical buildings (Municipality of Kalamaria).

MF1	MF1_p.att	MF2	MF3	MF3_p.att	MF3_de	MF4	MF4_r.sys	MF4_p.att.
3.35%	12.50%	22.13%	21.41%	3.24%	9.66%	10.53%	1.61%	5.08%

A major issue concerning green roofs implementation regards the demanding structural standards due to Greece's high seismic activity. Especially as regards existing buildings, this parameter could affect such measures to great extends. More specifically, the first Greek Seismic Code of 1954 was not revised until 1985, whilst the requirements regarding the weight loads of roofs remained the same until the new regulation of 2005. Table 20 shows that the majority of the buildings in the city center (Municipality of Kalamaria) are constructed before the revised Antiseismic Regulation. In this framework, extensive green roofs are the safer solution for the majority of the existing buildings by means of national retrofitting programs' implementation. In any other case, additional audits and studies are required in terms of each building's static efficiency. Hence, planning energy conservation measures for the existing urban environment presupposes the promotion of the extensive green roof type, especially concerning the urban existing building stock (Table 21).

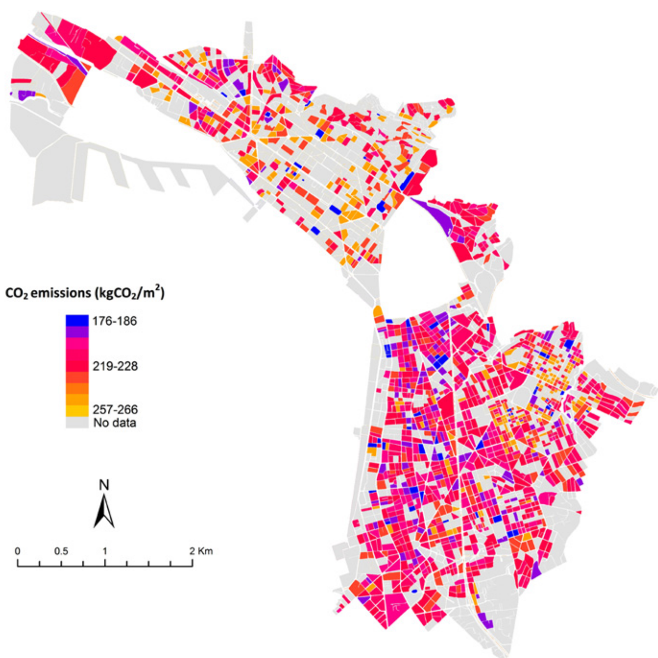

Fig. 9. CO_2 emissions per building block in the Municipality of Thessaloniki (residential building use).

5.3.2. *Opaque surfaces and openings*

As regards solid surfaces the aforementioned typical buildings provide us with the typical information needed. Namely, in the following tables both the window–wall ratio as well as the gross

Table 20
Available roof areas for the installation of green roofs according to the year of construction [m^2].

	Pre 1980	1980–today	Sum
Municipality of Thessaloniki	2,656,991	965,849	3,622,840
Municipality of Kalamaria	412,004	462,183	874,187

Table 21
Technical characteristics of green roofs by means of their static load [158].

Extensive	80–150 kg/m^2
Semi-intensive	150–280 kg/m^2
Intensive	at least 250 kg/m^2

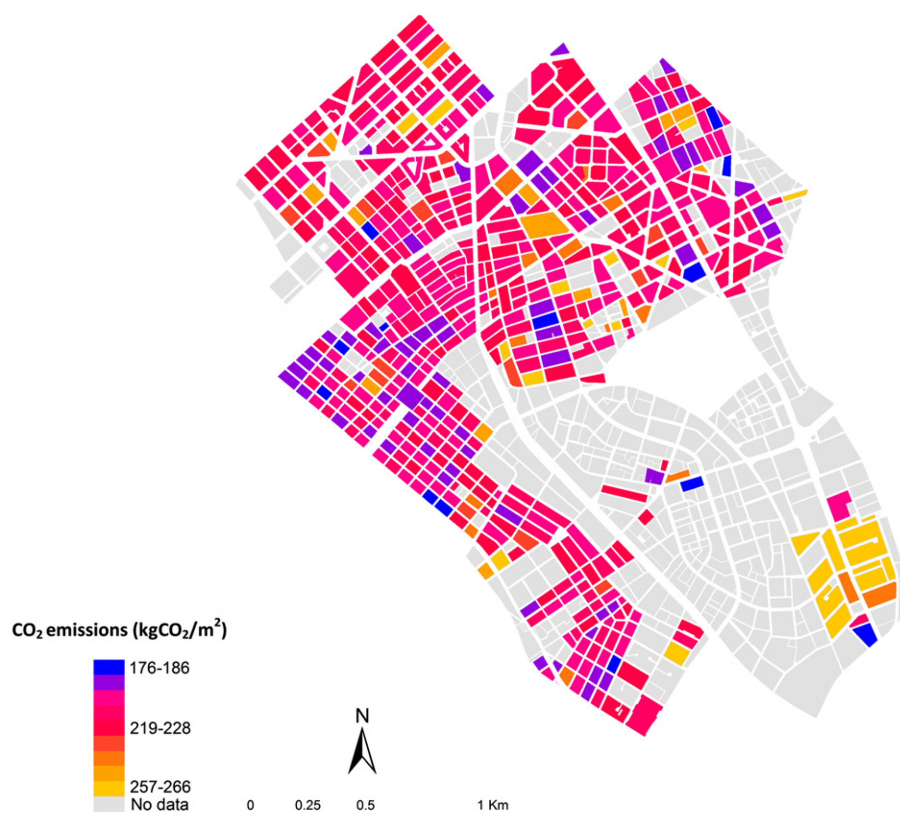

Fig. 10. CO_2 emissions per building block in the Municipality of Kalamaria (residential building use).

Table 22
Window–wall ratio and gross roof area for the building MF1.

	Total	North (315 to 45 deg.)	East (45 to 135 deg.)	South (135 to 225 deg.)	West (225 to 315 deg.)
Gross wall area [m^2]	815.19	298.8	109.38	299.52	107.5
Window opening area [m^2]	199.04	93.01	0	106.03	0
Window–wall ratio [%]	24.42	31.13	0	35.4	0
Gross roof area [m^2]	157.08				

Table 23
Window–wall ratio and gross roof area for the building MF2.

	Total	North (315 to 45 deg.)	East (45 to 135 deg.)	South (135 to 225 deg.)	West (225 to 315 deg.)
Gross wall area [m^2]	1788.05	512.73	381.41	512.5	381.41
Window opening area [m^2]	389.91	123.64	84.15	132.05	50.07
Window–wall ratio [%]	21.81	24.11	22.06	25.77	13.13
Gross roof area [m^2]	335.43				

Table 24
Window–wall ratio and gross roof area for the building MF3.

	Total	North (315 to 45 deg.)	East (45 to 135 deg.)	South (135 to 225 deg.)	West (225 to 315 deg.)
Gross wall area [m^2]	704.56	305.72	42.81	313.22	42.81
Window opening area [m^2]	157.87	73.27	0	84.6	0
Window–wall ratio [%]	22.41	23.97	0	27.01	0
Gross roof area [m^2]	240.00				

Table 25
Window–wall ratio and gross roof area for the building MF4.

	Total	North (315 to 45 deg.)	East (45 to 135 deg.)	South (135 to 225 deg.)	West (225 to 315 deg.)
Gross wall area [m^2]	1782.61	357.77	564.15	357.75	502.95
Window opening area [m^2]	238.3	32.04	24.17	51.93	130.16
Window–wall ratio [%]	13.37	8.95	4.28	14.52	25.88
Gross roof area [m^2]	279.04				

Table 26
Available exposed opaque vertical and horizontal surfaces for the implementation of thermal insulation (Municipality of Thessaloniki).

	Horizontal exposed opaque surfaces [m^2]	Vertical exposed opaque surfaces [m^2]	Total
Total	3,787,233	7,194,569	10,981,802
Until 1980	2,777,557	5,276,497	8,054,054
1980–present	1,009,677	1,918,072	2,927,749

Table 27
Available exposed opaque vertical and horizontal surfaces for the implementation of thermal insulation (Municipality of Kalamaria).

	Horizontal exposed opaque surfaces [m^2]	Vertical exposed opaque surfaces [m^2]	Total
Total	1,270,599	2,612,761	3,883,360
Until 1980	598,762	1,231,260	1,830,023
1980–present	671,686	1,381,217	2,052,902

roof area for each building, as well as the window to wall ratio are being depicted (Tables 22–25).

Based on the information of the above tables and the connection of the GIS maps to the relevant typologies, total surface area regarding openings, wall and flat roof areas and respective retrofit measures can be calculated. Hence, the analysis of our sample for the Municipality of Thessaloniki shows the majority of the residential buildings were constructed before 1980 and are

Table 28
Calculated minimum thermal insulation widths for each construction element (Climatic Zone C).

	Pilotis floor	Flat roof	Brick walls	Bearing structure
Thermal insulation width [m]	0.08	0.08	0.06	0.07

Table 29
Average total expected costs for retrospective thermal insulation measures for the Municipality of Thessaloniki and Kalamaria.[a]

	Vertical surfaces [m^2]	price [€/m^2]	Expected costs	Horizontal surfaces [m^2]	price [€/m^2]	Expected costs	Total costs
Municipality of Thessaloniki	5,276,497	50	263,824,850	2,777,557	40	111,102,280	374,927,130
Municipality of Kalamaria	1,231,260	50	61,563,000	598,762	40	23,950,480	85,513,480
Total	**6,507,757**		325,387,850	**3,376,319**		**135,052,760**	**460,440,610**

[a] Refers to retrofitting measures for all buildings constructed before 1980.

therefore categorized in Class B (see also Section 2.2). As a result, they were constructed before the implementation of the first Thermal Insulation Regulation. More specifically, the overall exposed vertical and horizontal opaque surfaces for the Municipality of Thessaloniki and Kalamaria are presented in Tables 26 and 27.

With respect to retrospective thermal insulation implementation measures, the surfaces of buildings constructed before 1980 are of vital importance. In this line of thought, according to the respective Technical Directive of the KENAK in accordance with the European EPBD Guidelines, the mean U-value of the bearing structure for buildings constructed before 1980 is 3.4 W/m^{2}K, whereas fort the brick walls the respective value reaches 2.2–3.05 W/m^{2}K [135]. Similarly, for horizontal surfaces, the U-value is 3.05 W/m^{2}K and 2.75 W/m^{2}K for flat roofs and Pilotis floors respectively [135]. For a moderate scenario of targeted energy upgrading retrofitting national plan, aiming at heating energy reduction, thus improvement of the buildings' envelope, the necessary minimum width of thermal insulation material was calculated. More specifically, Table 28 shows these minimum widths for insulation materials with a thermal conductivity rate of 0.035 W/mK, in order to cover the minimum requirements according to the new legislative framework of KENAK for the Climatic Zone C.

In the case of an ETICS system the thermal insulation is assumed to be applied with the same insulation material for the vertical exposed surfaces. In this line of thought and based on the official pricing for thermal insulation materials, proposed by national programmes [159] the average total costs for retrospective thermal insulation of existing buildings for the municipality of Thessaloniki and Kalamaria are being presented (Table 29). Hence, an overall thermal insulation retrofitting initiative by the state, would eventually inquire the partial or full capital funding of 460,440,610 euros in order to achieve better energy behavior of the urban residential building stock with respect to a large part of the city of Thessaloniki.

Moreover, these costs would raise more in the case of a larger sample, which will include buildings constructed during 1980–1990, a rather dull period as regards the implementation of thermal insulation in constructions [15].

It is obvious that greater widths of thermal insulation could be studied as for their implementation's costs and would assuredly lead to better energy conservation results.

5.3.3. Built form and A/V ratio

According to our assessment tool the mean A/V ratio for the Municipality of Thessaloniki is 0.42 and 0.53 for the Municipality of Kalamaria. Moreover, the U_m values of the existing buildings are presented in Table 4. Hence, in a case of energy refurbishment and retrospective insulation of the building the respective U_m values should drop to 0.95–0.86 m^{-1} respectively in order to comply with the minimum requirements. More specifically, it becomes obvious that Municipality of Thessaloniki consists of more compact buildings, a fact that explains the relative low energy consumption, regardless the lack of thermal insulation on the buildings' envelope [157]. On the other hand, detached MF-buildings domain the Municipality of Kalamaria and are connected to higher energy consumption rates, as analyzed in Section 5.2. In the case of large scale retrofitting, such details may play a very important role; as the buildings are more compact, smaller widths of insulation could be used in order to achieve the minimum requirements of KENAK concerning the mean U_m value. In terms of economic feasibility, and based on the relevant assumptions in the previous chapter, these figures could determine, by and large, factors such as the quality of the materials in terms of their thermal conductivity properties, specific widths and even the nature of the state's funding supports. In this framework, urban density could influence respective retrofit strategies to great extends.

6. Conclusions

"God made the country, and man made the town" said William Cowper in 1785. Given the fact that over 200 years have passed, and the structure of cities has dramatically changed, this saying is more relevant than ever. Over this time, cities grew, expanded in height and width, with less environment friendly materials, less green and more inhabitants. Thus, energy efficiency is now a part of a holistic sustainable management approach for urban environments. Great efforts towards this direction have to be made, whilst single solutions cannot offer the covetable results. The need to connect urban topography, typologies of buildings, indoor air quality and urban free spaces of high quality, within a framework of urban sustainable development, is immense.

The authors believe that GIS based assessment tools can significantly contribute to energy efficiency management. Hence, the proposed methodology aims at the systematic collaboration of available data, regarding buildings, occupants, urban topography, climatic conditions and many more, in order to better serve this purpose. In this line of thought, besides the hereby presented research parameters, our scheme allows the further elaboration of information input, concerning shading control in buildings, the estimation of CO_2 reduction in the urban built environment according to various retrofit scenarios, as well as the implementation cool materials, the potential of RES on vertical building elements and many more.

Conclusively, GIS-maps can become a powerful mechanism during the process of energy policy planning in a city scale and provide vital information as regards urban energy efficiency. Bottom line is, as Ben Stein said, "somewhere there is a map of how it can be done".

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